



# Liquid Argon Technology for Neutrinos

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7th IDS-NF Plenary Meeting



# Talk Outline

- Introduction to Liquid Argon detectors for neutrinos.
- The MicroBooNE Experiment
- Future directions.

# Introduction

- Liquid Argon Time Projection Chambers (LArTPCs) combine fine-grained tracking and calorimetry, and appear scalable to very large size.
- U.S. efforts to develop LArTPCs have expanded significantly in recent years.
- These efforts are aimed at developing the technology for a multi-kiloton detector that could be used to do a variety of physics (accelerator neutrinos, proton decay, astrophysics, ...)
- “Smaller” scale detectors, O(100 tons), also offer opportunity for important physics measurements.

# Why Noble Liquids for Neutrinos?

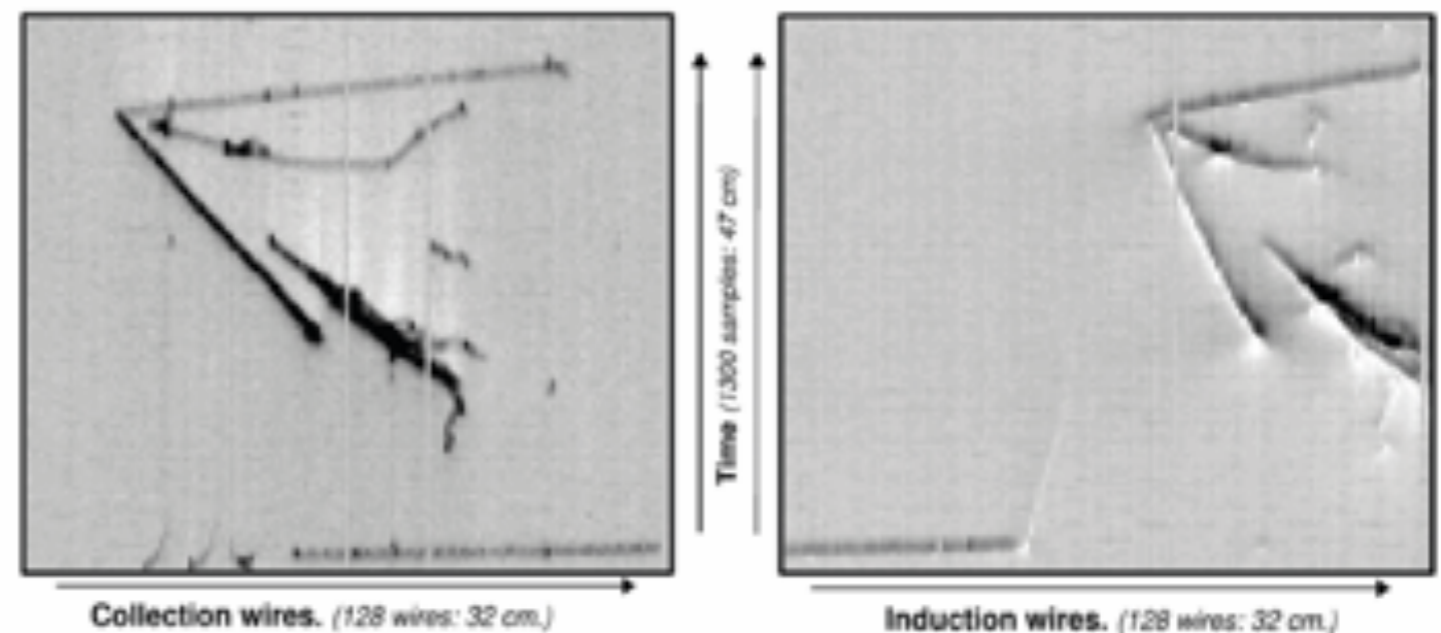
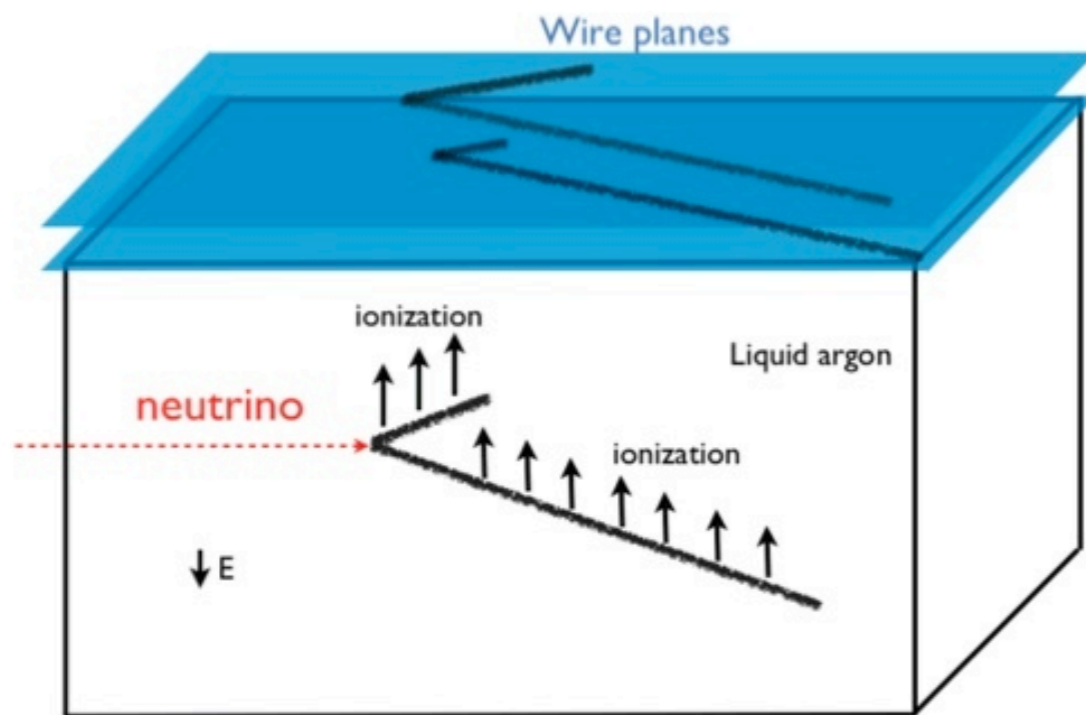
- Abundant ionization electrons and scintillation light can both be used for detection.
- If liquids are highly purified ( $<0.1\text{ppb}$ ), ionization can be drifted over long distances.
- Excellent dielectric properties accommodate very large voltages.
- Noble liquids are dense, so they make a good target for neutrinos.
- Argon is relatively cheap and easy to obtain (1% of atmosphere).
- Drawbacks?...no free protons...nuclear effects unavoidable.



Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm <sup>3</sup> ]	0.125	1.2	1.4	2.4	3.0	1
Radiation Length [cm]	755.2	24.0	14.0	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3.0	3.8	1.9
Scintillation [ $\gamma$ /MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation $\lambda$ [nm]	80	78	128	150	175	

# Liquid Argon Neutrino Detectors

- Neutrino interactions in the TPC produce charged particles that ionize the argon as they travel.
- Ionization is drifted along E-field to wireplanes, consisting of wires spaced ~millimeters apart.
- Location of wires within a plane provides position measurements...multiple planes give independent views.
- Timing of wire pulse information is combined with known drift speed to determine drift-direction coordinate.



Images from ICARUS 50-liter TPC.

Refs:

1.) *The Liquid-argon time projection chamber: a new concept for Neutrino Detector*, C. Rubbia, CERN-EP/77-08 (1977)

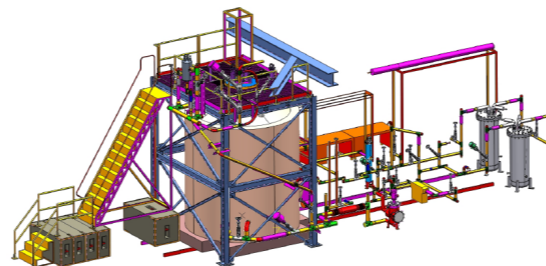
# Liquid Argon Efforts at Fermilab

Development focused on scaling LArTPCs to sizes necessary for long-baseline experiment.

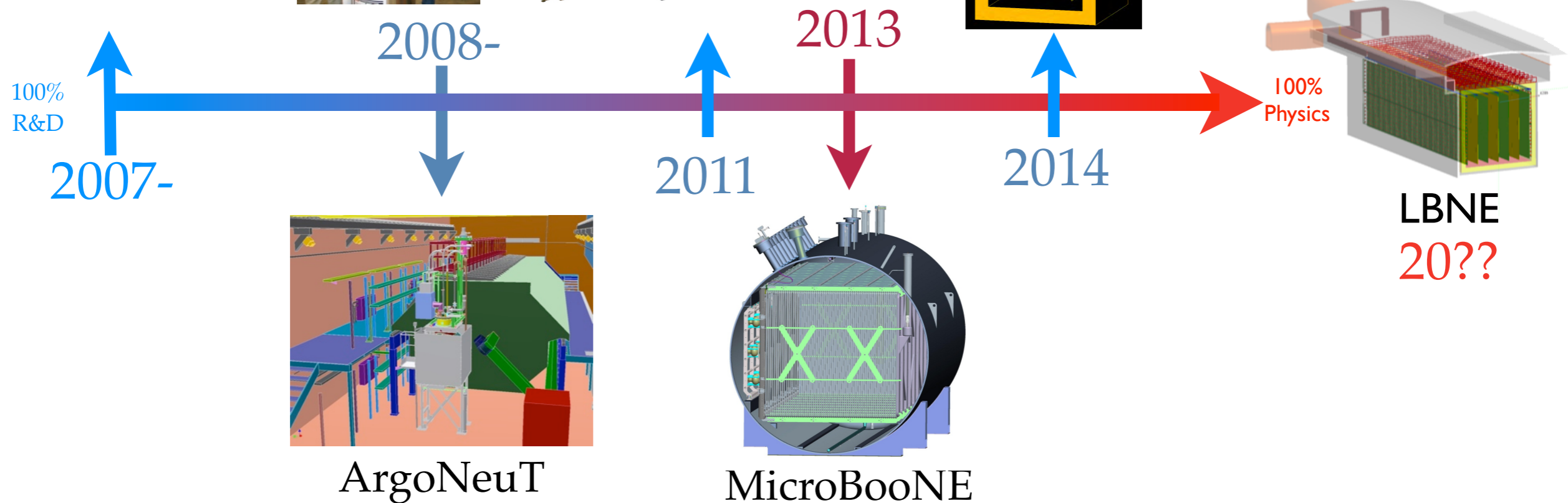
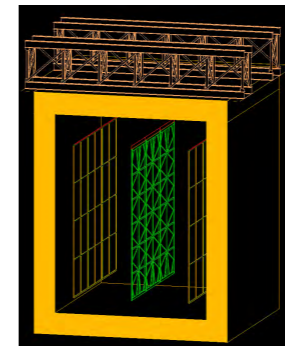
Materials/Electronics Test Stand



L.A.P.D.



1-kTon  
Prototype

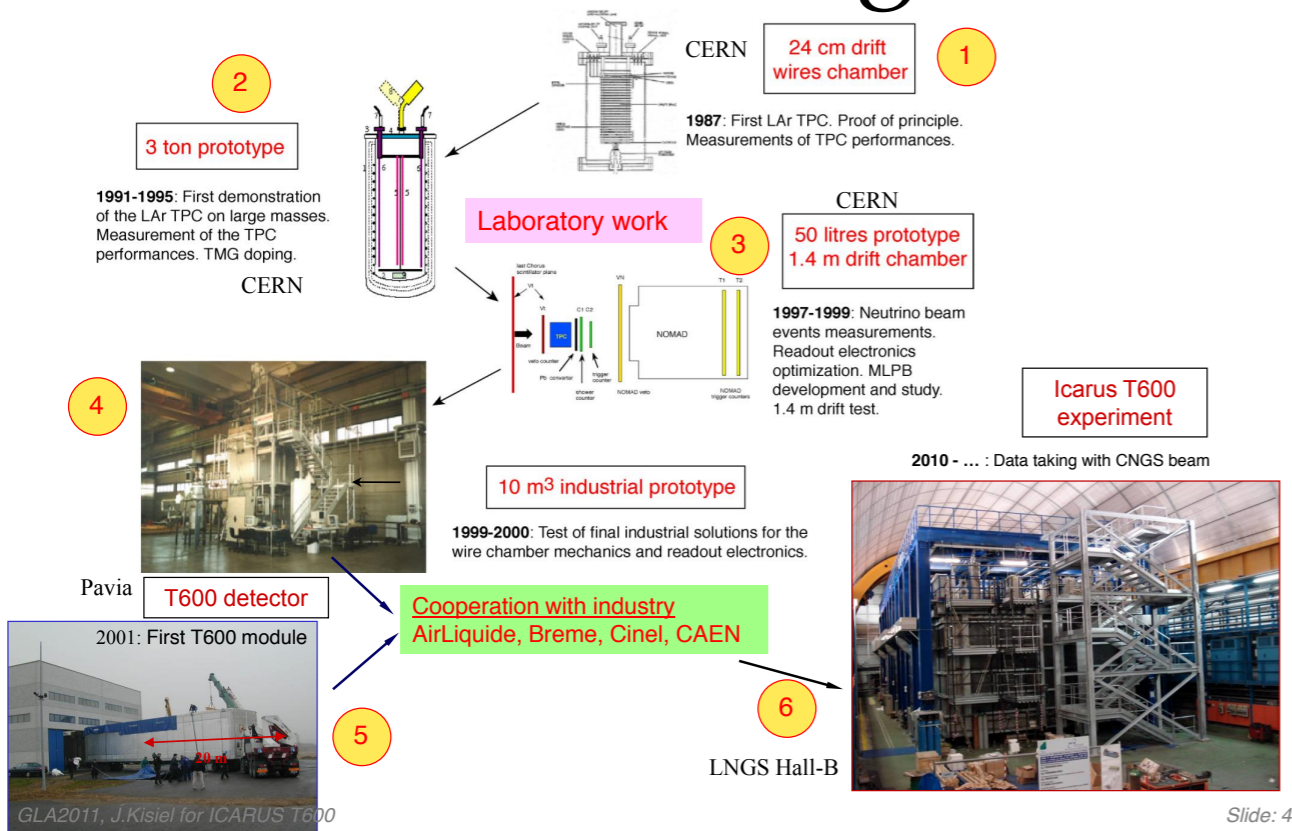


Refs:

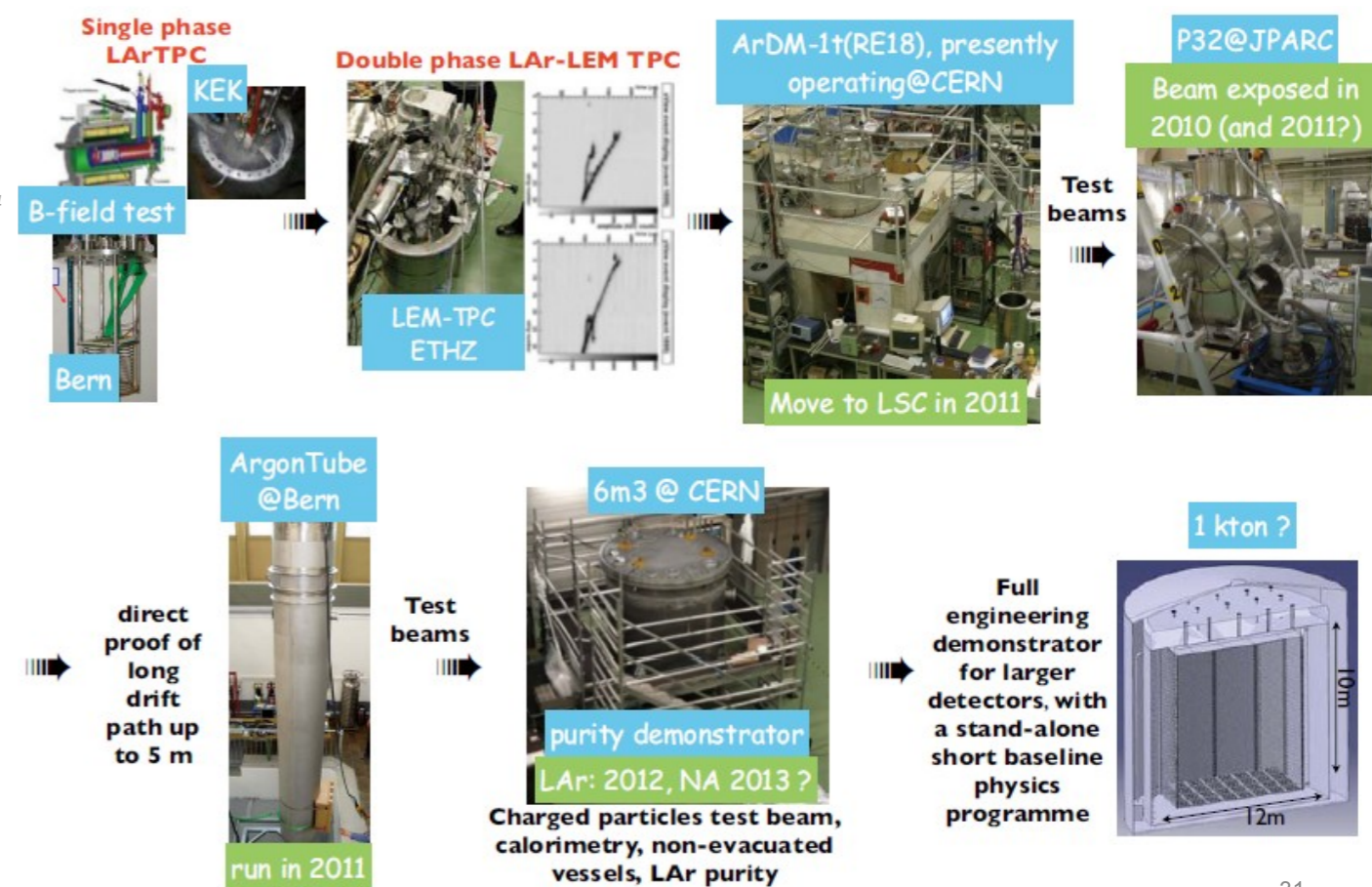
- 1.) A Regnerable Filter for Liquid Argon Purification Curioni et al, NIM A605:306-311 (2009)
- 2.) A system to test the effect of materials on electron drift lifetime in liquid argon and the effect of water Andrews et al, NIM A608:251-258 (2009)

# Liquid Argon Worldwide

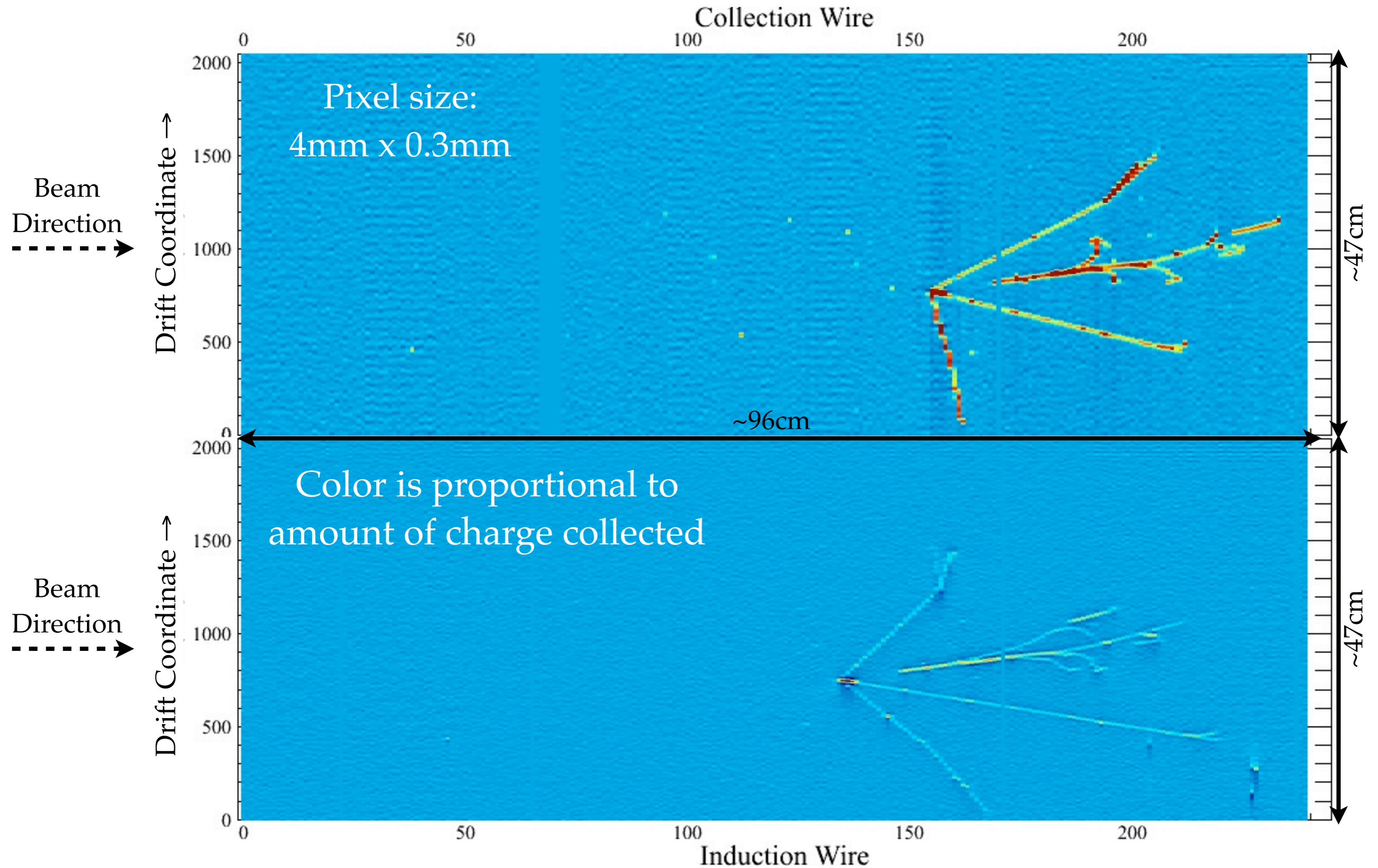
## ICARUS Program



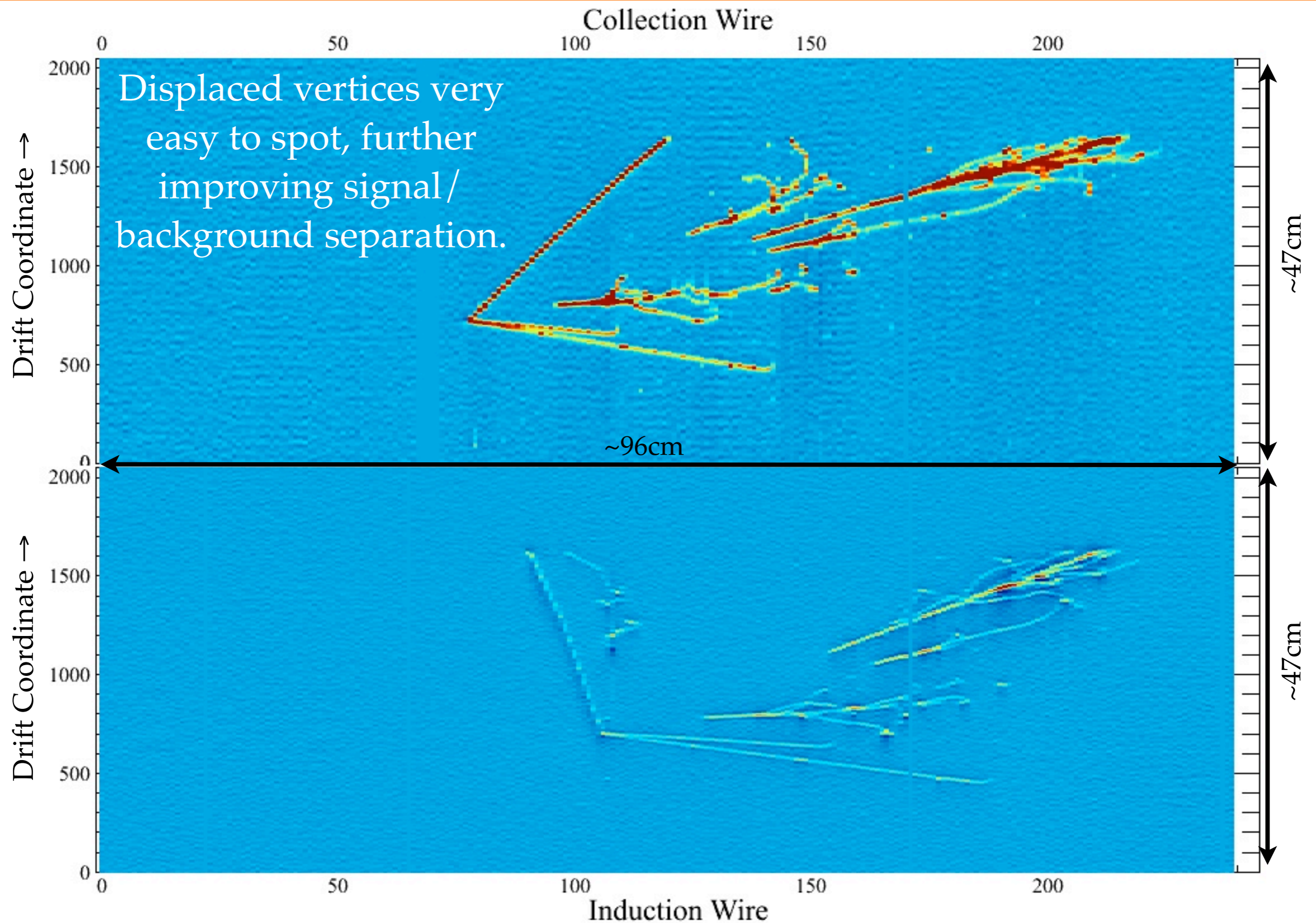
## Europe/Japan Program



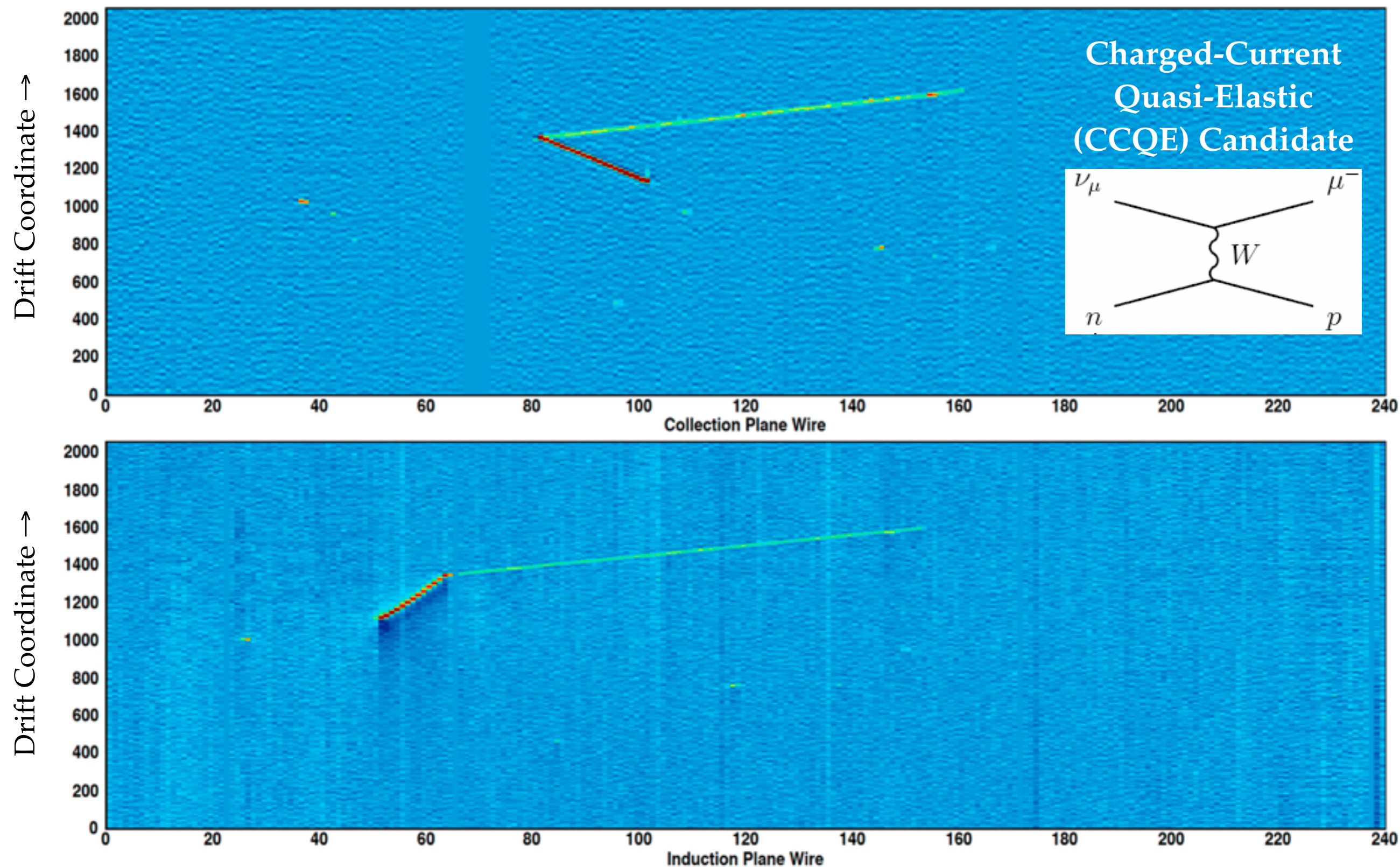
# ArgoNeuT Data Event



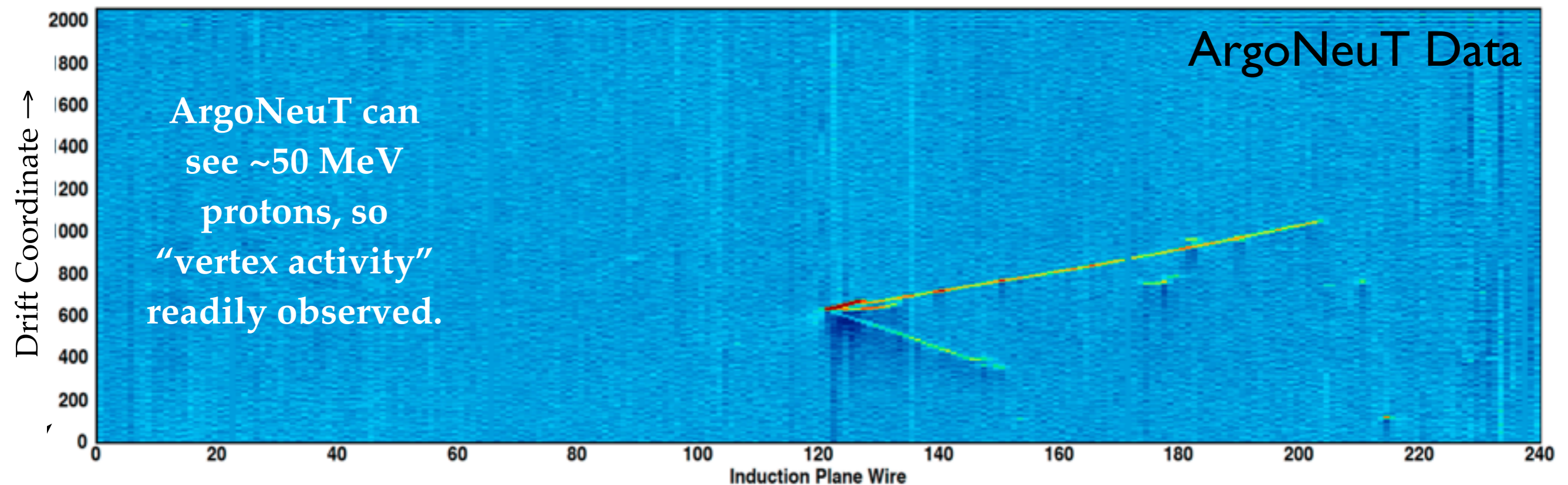
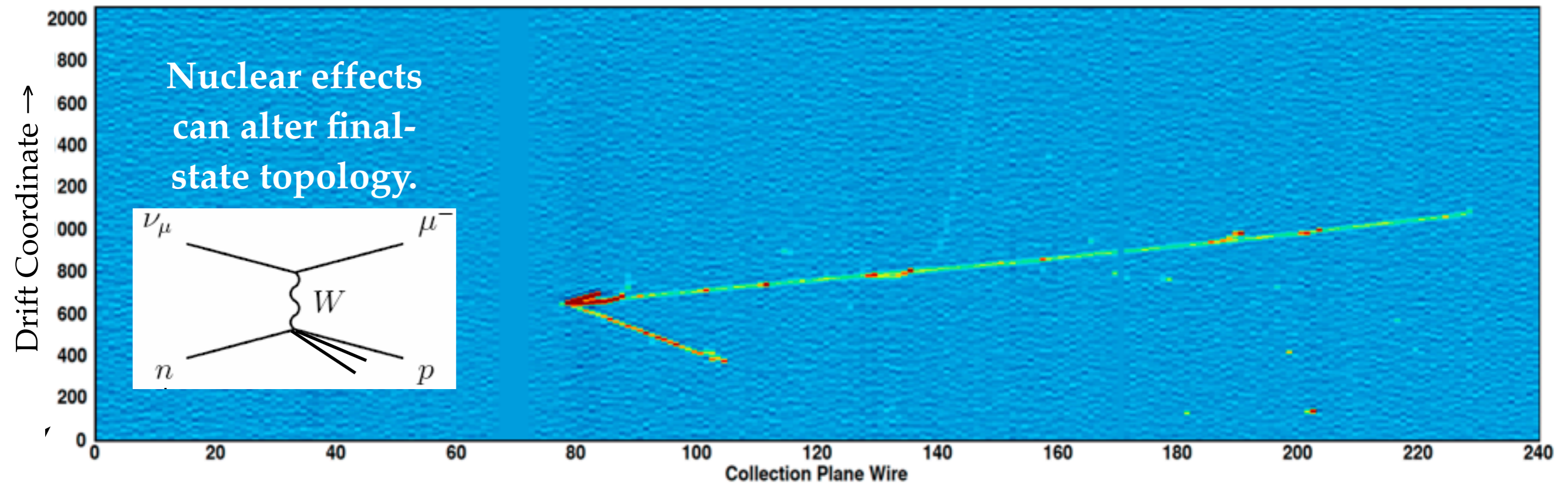
# ArgoNeuT Data Event



# ArgoNeuT Data Event



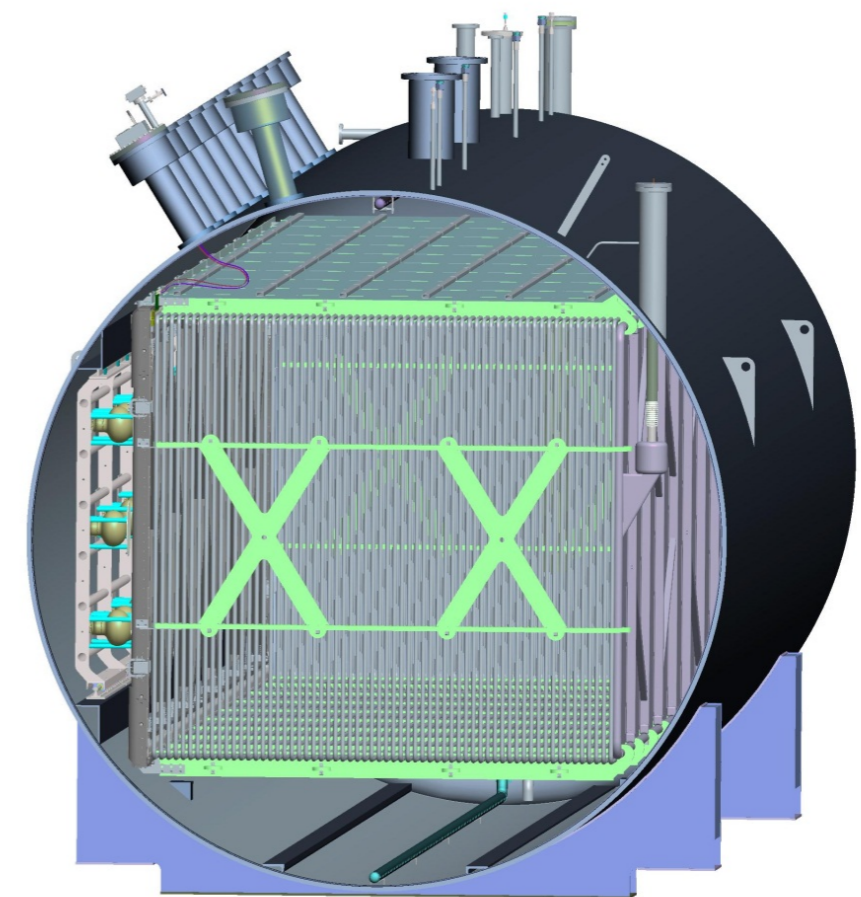
# ArgoNeuT Data Event



# MicroBooNE

- MicroBooNE will operate in the Booster neutrino beam at Fermilab starting in late 2013.
- Combines timely **physics** with **hardware** R&D necessary for the evolution of LArTPCs.
  - ▶ MiniBooNE low-energy excess
  - ▶ Low-Energy Cross-Sections
  - ▶ Cold Electronics (preamps in liquid)
  - ▶ Long drift (2.5m)

Cryostat Volume	150 Tons
TPC Volume (l x w x h)	89 Tons (10.4m x 2.5m x 2.3m)
# Electronic Channels	8256
Electronics Style (Temp.)	CMOS (87 K)
Wire Pitch (Plane Separation)	3 mm (3mm)
Max. Drift Length (Time)	2.5m (1.5ms)
Wire Properties	0.15mm diameter SS, Cu/ Au plated
Light Collection	~30 8" Hamamatsu PMTs



- ➡ Joint NSF / DOE Project
- ➡ \$1.1M NSF MRI for TPC, PMTs

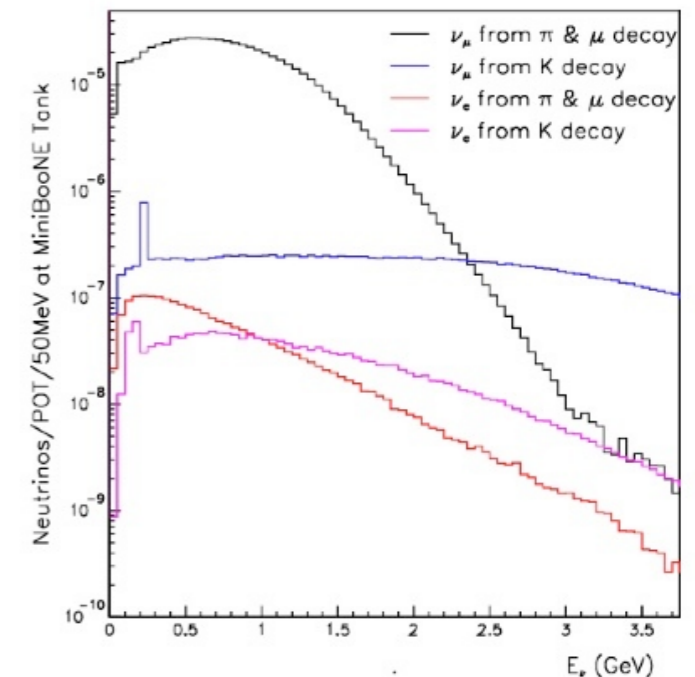
- ★ Stage 1 approval from Fermilab directorate in June 2008
- ★ DOE CD-0 (Mission Need) in October 2009
- ★ DOE CD-1 June 2010
- ★ DOE CD-2/3a (September 2011)

# MicroBooNE: Location

- MicroBooNE will sit on surface in on-axis Booster beam (BNB), and off-axis NuMI beam.
- Liquid Argon Test Facility will be located directly upstream of MiniBooNE enclosure. L=470m.
- Large event samples will allow a variety of cross-section measurements.

	BNB	NuMI
Total Events	145k	60k
$\nu_\mu$ CCQE	68k	25k
NC $\pi^0$	8k	3k
$\nu_e$ CCQE	0.4k	1.2k
POT	$6 \times 10^{20}$	$8 \times 10^{20}$

Projected Event Rates for MicroBooNE in 2-3 years.

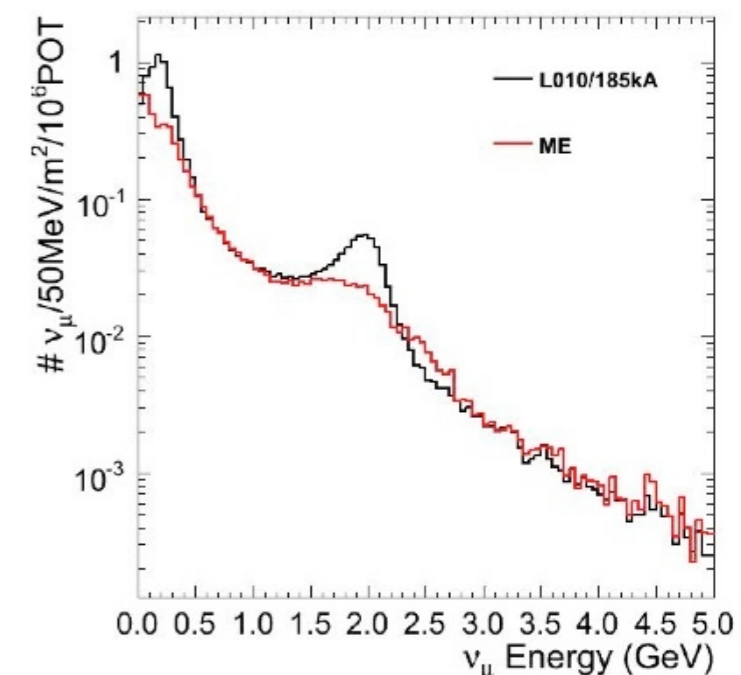


Neutrino Beams at Fermilab



MicroBooNE will be located in Liquid Argon Test Facility

Booster Flux

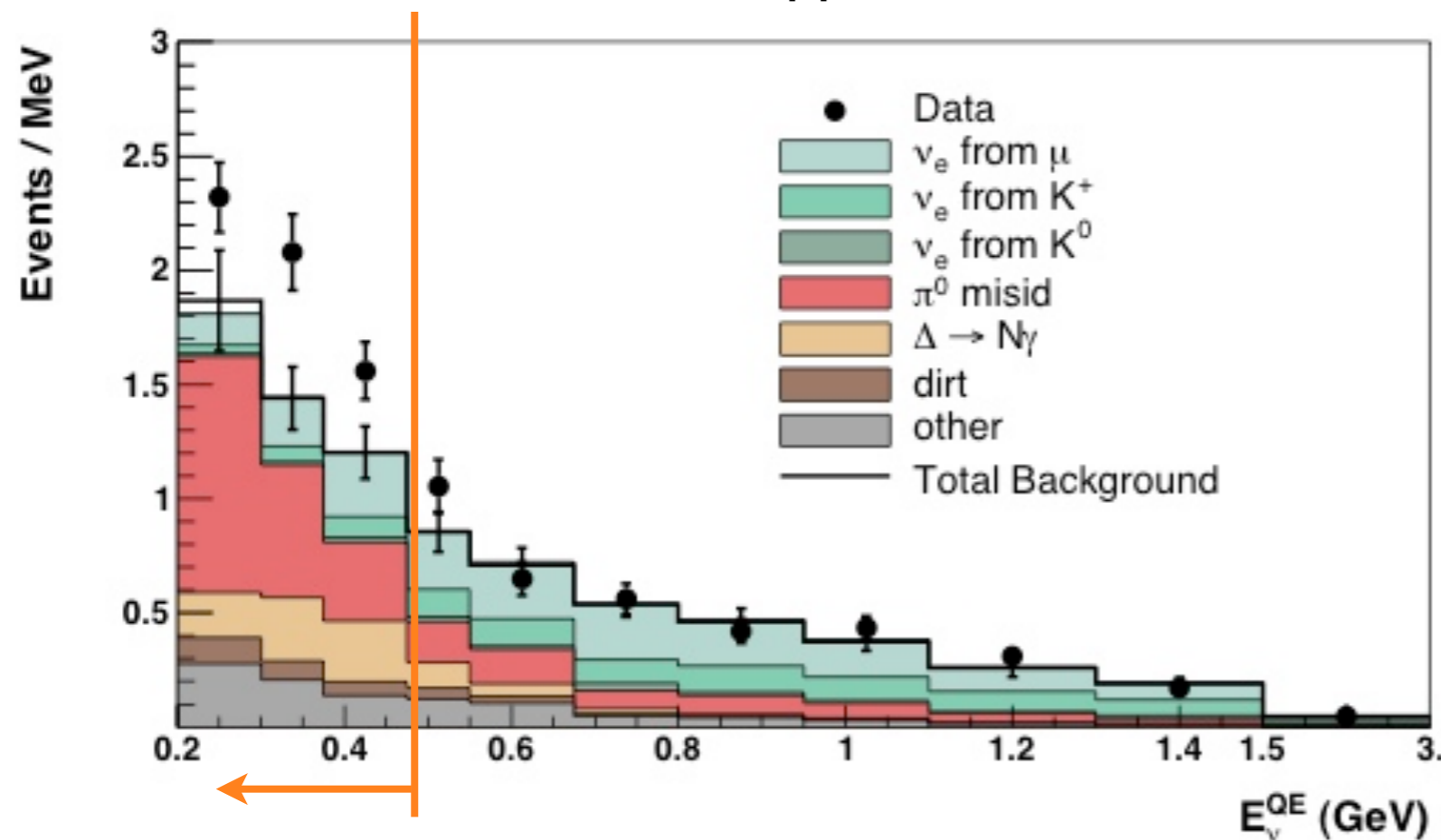


NuMI Off-Axis Flux

# MicroBooNE: Physics

- Address the MiniBooNE low energy excess
  - ▶ MiniBoone is a Cerenkov detector that looked for  $\nu_e$  appearance from a beam of  $\nu_\mu$
  - ▶ Does MicroBooNE confirm the excess?
  - ▶ Is the excess due to a electron-like or gamma-like process?

MiniBooNE  $\nu_e$  Appearance Result



MiniBooNE Result Excess

200-300MeV:  $45.2 \pm 26.0$  events

300-475MeV:  $83.7 \pm 24.5$  events

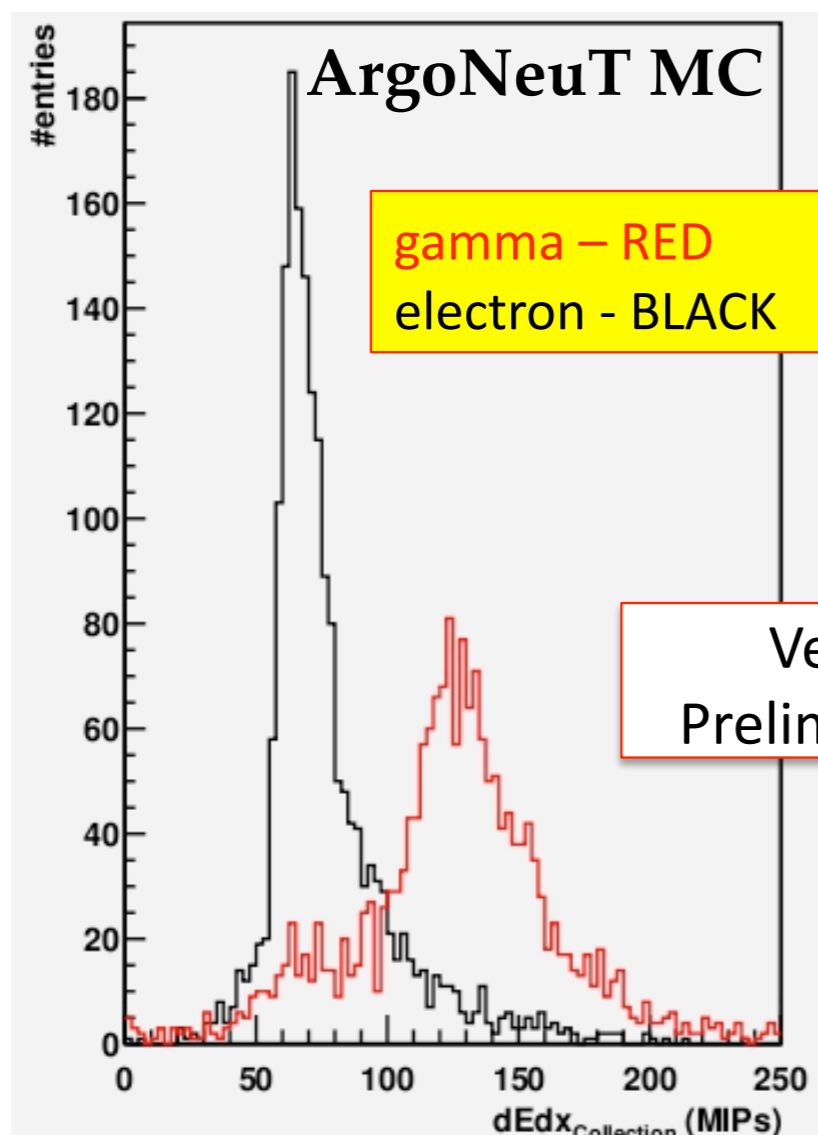
MicroBooNE will have  $\sim 5.5\sigma$  significance  
for electron-like excess,  $\sim 4\sigma$  for photon-  
like excess.

Refs:

1.) *Unexplained Excess of Electron-Like Events From a 1-GeV Neutrino Beam* MiniBooNE Collaboration, Phys. Rev. Lett. 102, 101802 (2009)

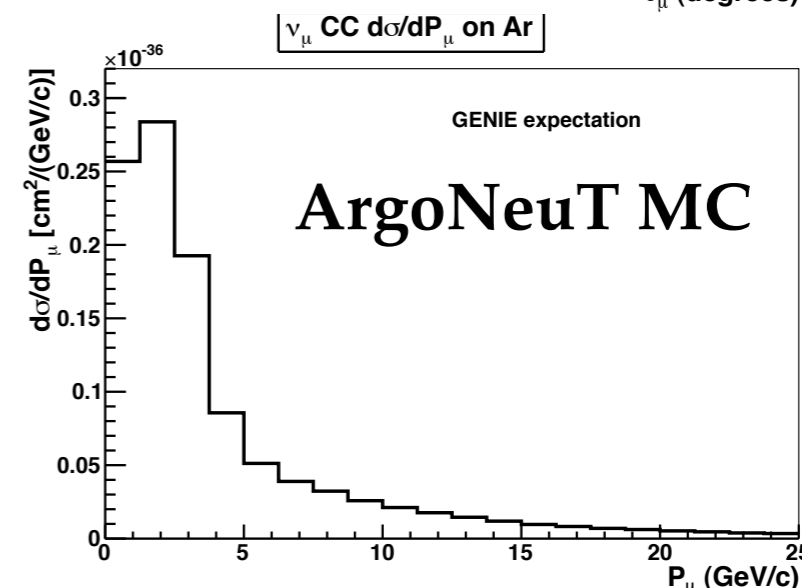
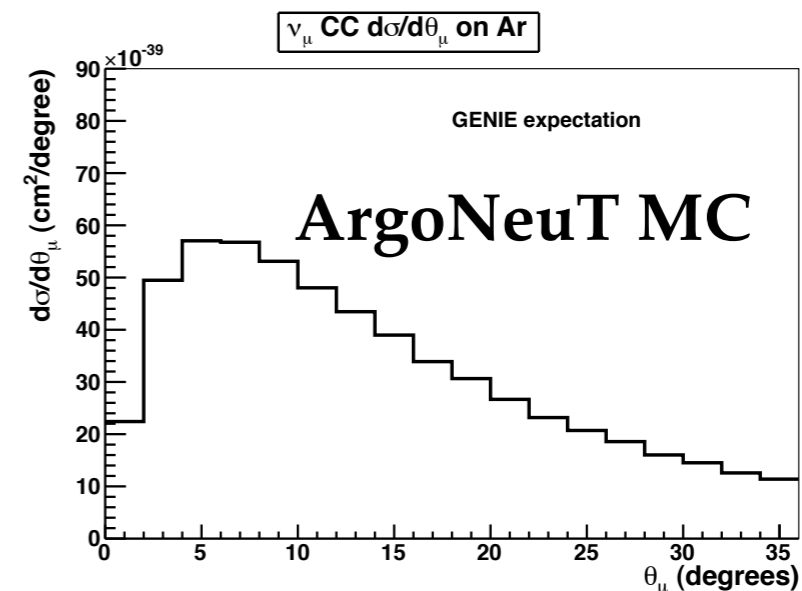
# MicroBooNE: Physics

- Prove effectiveness of electron/ gamma separation technique (using dE / dX information).
- Low Energy Cross-Section Measurements (CCQE, NC  $\pi^0$ ,  $\Delta \rightarrow N\gamma$ , Photonuclear, ...)
- Continue development of automated reconstruction (building on ArgoNeuT's effort).



dE / dx in first 5cm of  
Simulated / Reconstructed  
Gamma / Electron showers.

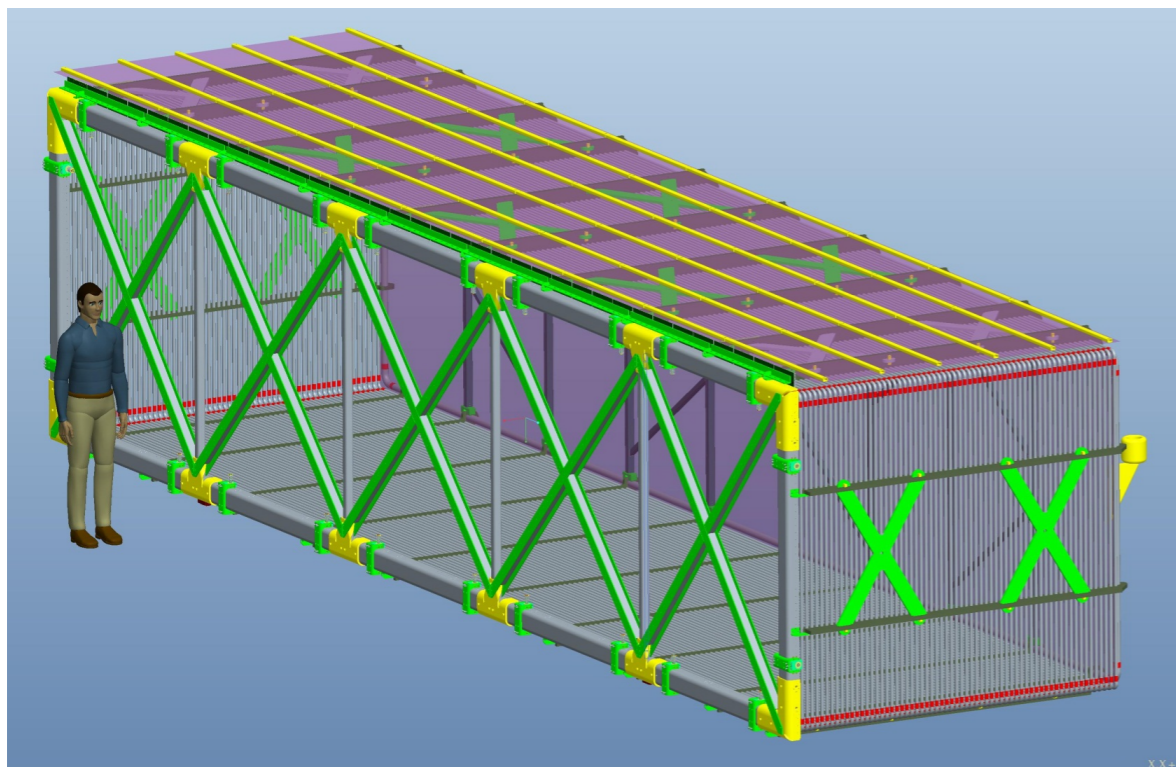
Very  
Preliminary



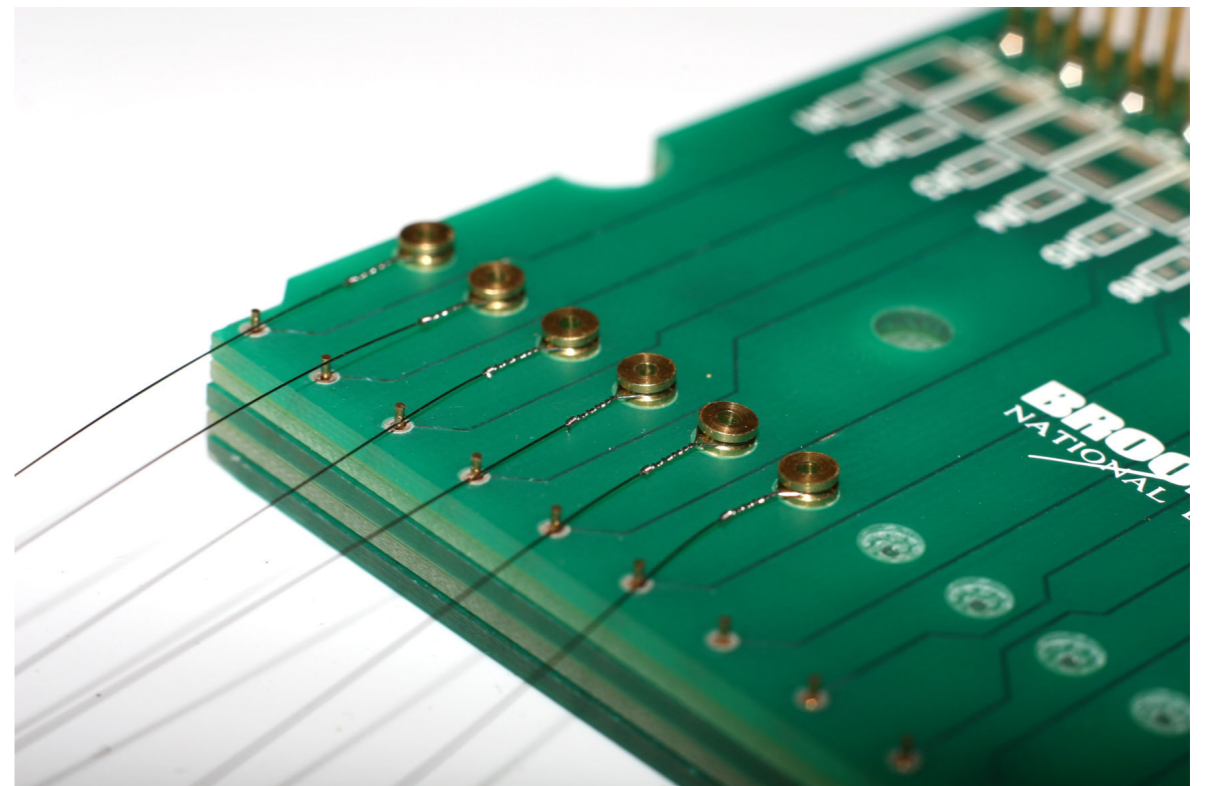
Inclusive CC cross-section in  
neutrino-mode (simulated/  
reconstructed / analyzed MC)

# MicroBooNE: TPC

- TPC has 3 instrumented wireplanes (Two Induction at  $\pm 60^\circ$  from vertical, One Collection with vertical wires).
- Cathode is held at -125kV, setting up 500V / cm drift field.
- Wires are individually terminated around brass ferrules, then positioned on wire carriers.



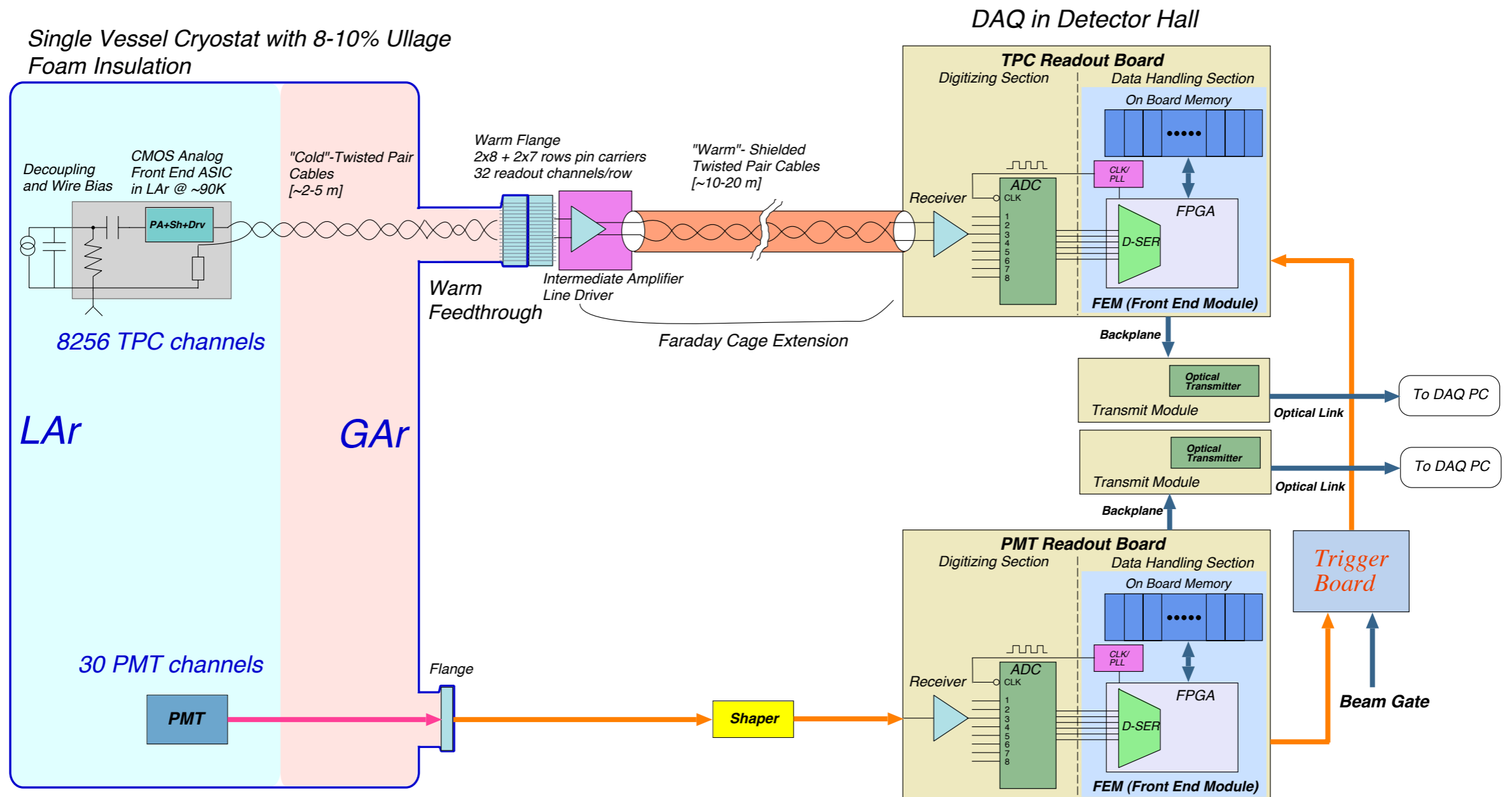
Schematic of MicroBooNE TPC



Prototype wires and wire carrier boards.

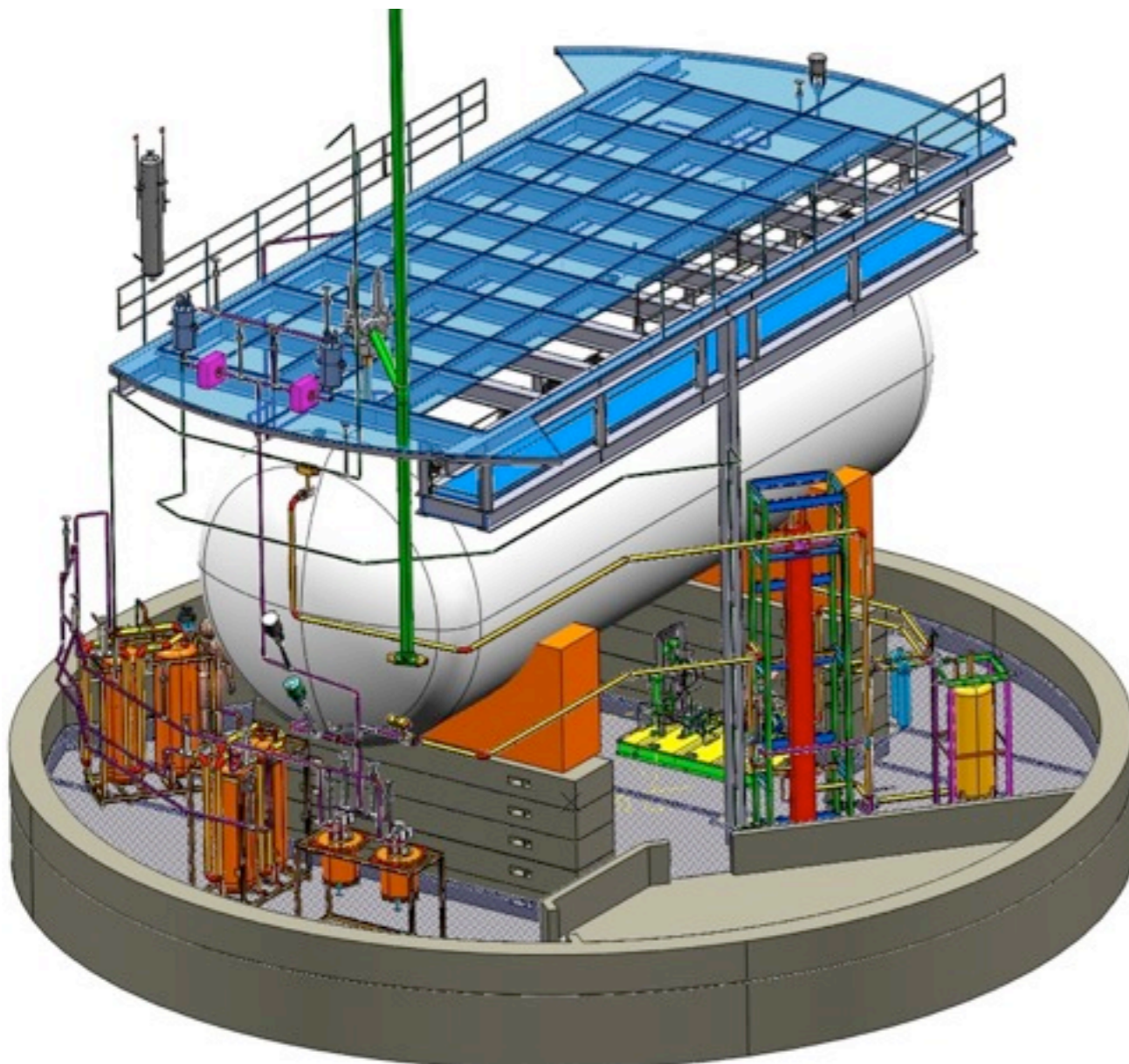
# MicroBooNE: Electronics

- CMOS preamplifiers located in liquid, attached to TPC.
- 12-bit ADCs sampled at 2MHz (i.e. - 500ns per sample) for 4.8ms (x3 drift window).
- 1-hour data buffering for Supernova detection signal from SNEWS.



# MicroBooNE: Cryogenics

- Cryogenic system consists of filters/pumps/etc... for circulating and purifying LAr.
- Cryostat is evacuable (though the plan is not to evacuate) and foam insulated.



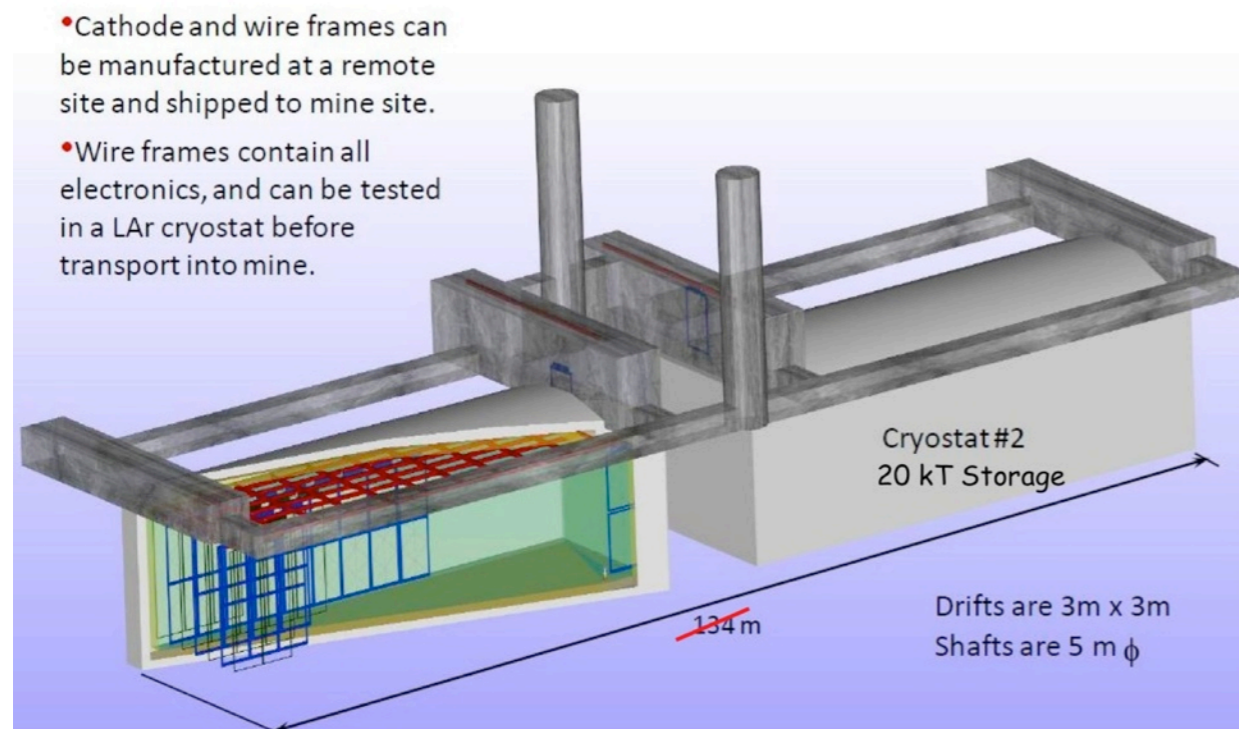
Schematic of MicroBooNE Layout



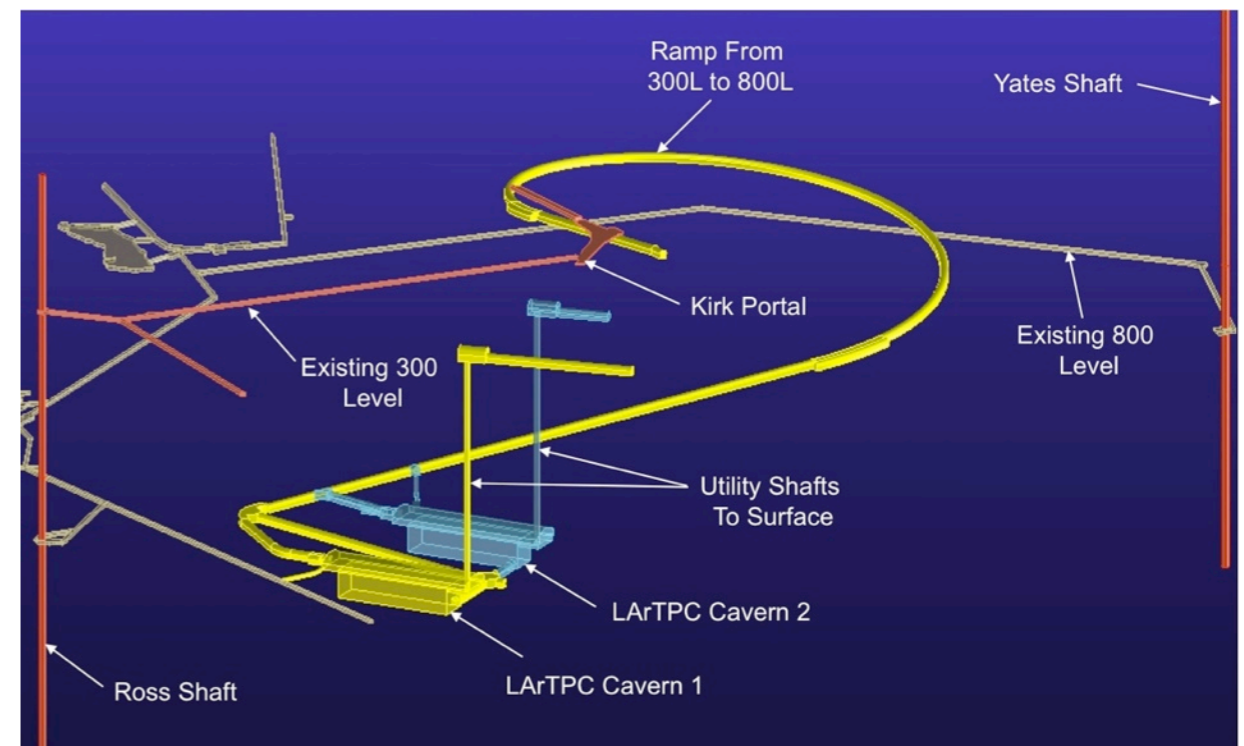
LAPD @ Fermilab

# Massive LArTPC Detectors

- Description here is the Reference design for the LBNE project.
- LArTPC at DUSEL would be two ~20 kTon modules.
- Detector located at the 800ft level at DUSEL.



~20 kTon LArTPC module(s)



800-ft. level layout.

Cryostat Volume	~25 kTons
TPC Volume	~16.7 kTons
# Readout Wires	~645000 (128:1 MUX)
Wire Pitch	~3 mm
Electronics Style (Temp.)	CMOS (87 K)
Max. Drift Length	~2.5m
Light Collection	TBD

# Liquid Argon for Neutrino Factory

# Conclusion

- Liquid Argon detectors provide exceptional capabilities for neutrino physics, and there is significant R&D ongoing at Fermilab, and worldwide, to develop this technique for very large scales.
- MicroBooNE is the next major step in the U.S. plan for LArTPCs, and it will provide interesting physics and hardware development.
- Neutrino Factory...